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Final Report

R-86-07-0026

Fine Grinding and Air Classification of Clears
from HRS Flour Milling into Wheat Protein
Concentrate and a Baker's Flour

Conducted by Dr. F. Sosulski

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September 30, 1986 - September 30, 1989

Project: Fine grinding and air classification of clears from HRS flour
milling into wheat protein concentrate and a Baker's flour.

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ABSTRACT - PROJECT NO. R-86-07-0026

WHEAT PROTEIN CONCENTRATES FROM LOW-GRADE FLOURS

F. Sosulski

Refined wheat gluten has become a common ingredient in high fiber and variety breads to strengthen the dough and increase loaf volume. As an alternative to this expensive wet-processed protein, research was conducted on fine grinding and air classification of the outer endosperm flours that have a high protein content but low market value. The air classifier provided two products, a fine fraction that included much of the flour protein and a coarse fraction that was depleted in protein and enriched in starch. The wheat protein concentrate at 35% protein content was found to be comparable or better than gluten in wheat or oat bran breads, especially at higher fiber levels. Since two-thirds of the product from the classifier was the coarse fraction, it was important to find a major market for the by-product. Experiments demonstrated that this flour could be blended into the commercial bakers' flour stream, which has a market value about twice that of the original low-grade flour.

<u>Personnel on project</u>	<u>Position</u>	<u>Period</u>	<u>Time %</u>
Dr. Frank Sosulski	Principal Investigator	1986-89	10
Dr. Robert Reichert	Co-Investigator, PBI	1986-88	10
Mr. Derek Nowakowski	M.Sc. candidate, Advisor	1986-88	10
Dr. Ann Walker	Collaborator, University of Reading, UK.	1986-88	5
Mr. Jacek Nowak	Principal Technician	1986-88	100
Mr. Prakash Bhirud	Ph.D. candidate	1989	15
Mr. El-Sayed Abdel-Aal	Postdoctoral Fellow	1989	100
Mr. Kuang Wu	Senior Technician	1989	10
<u>Budget</u>			
	1986-87	\$34,440	
	1987-88	\$34,440	
	1988-89	\$34,440	

EXECUTIVE SUMMARY

The requirements for gluten supplementation of modern variety breads and buns have increased markedly during the past decade although the gluten extraction industry is in economic decline because of low gluten yields, high energy costs and pollution problems. The objective of the present study was to evaluate a dry system for preparing wheat protein concentrates from low quality, outer endosperm flours which are rich in gluten-forming proteins. The two-stage process involves the regrinding of wheat flours to fracture the endosperm chunks into individual starch granules and fine pieces of other components like protein and cell wall fragments. In the second stage, the finely ground material is passed through an air vortex to separate the fines from the dense granules, the protein in the fines being diluted by the significant proportions of small starch granules, broken starch pieces as well as fiber and other cell components.

An initial study of a fifth break flour, originating from the outer endosperm, and a first middling flour, from the center of the endosperm, demonstrated that two passes through a pin mill or an attrition mill was necessary to reduce either flour to a particle size that would approximate the volume of a starch granule (30-40 μ m diameter). But the fifth break flour suffered only 18-10% of starch damage as compared to 27-31% for the middling flour. Also the fifth break flour yielded 28% of a high protein (36% protein, 48% starch on a dry basis) fine fraction that gave comparable results to gluten as supplements in a wide range of bread formulations.

An unexpected result was the excellent breadmaking quality of the coarse fractions, when blended with bakers' flours. Since this was the major product of air classification of break flours, it meant that all products of the process were value-added. On the other hand, the fines or wheat protein concentrate from the middling flour, which contained only 25% protein, failed to improve the loaf volumes of soft wheat, triticale and rye flours.

Then, six break flours from the hard red spring flour mill, representing 10.5%

of the total flour production, were processed, individually and in a blend, by pin milling and air classification, to show that each could be fractionated into high and medium protein fractions with greater efficiency than the outermost fifth break flour. On the average, these fine fractions, at 35% yield, contained 31% protein, 55% starch, 2% ash and 4% fat. The coarse fractions had 16.5% protein, 79% starch, 0.5% ash and 1.5% fat. Obviously, shifting more of the fine starch into the coarse fraction would greatly enhance the efficiency of the process. Data was obtained to show that attrition milling systems should be investigated more fully as a step in this direction.

A complete series of five break and four middling flours were obtained from a second flour mill and all flours were processed through the pin milling and air classification system to again demonstrate that the third, fourth and fifth break flours were the best flours for the process, and these flours are the cheapest flours at the mill because of their limited markets. The fines (wheat protein concentrates) were incorporated in fiber-enriched breads containing up to 25% of wheat bran or oat bran and proved to be more effective than wheat gluten in the improvement of loaf volumes and bread crumb characteristics.

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1. BACKGROUND AND OBJECTIVES

The markets for Hard Red Spring (HRS) wheats grown in Western Canada have been restricted, increasingly, by regulations of the EEC. Their bakers require strong gluten flours for improvement in the baking performance of local European winter wheats. The deficiency is being met, to some extent, by increased production of gluten in the EEC. But soft wheats give a low yield of gluten, less than 12-13%, and the strength is not comparable to gluten from HRS. Bakers can make acceptable breads by adding high levels of dough oxidants and conditioners but their usage is prohibited in some EEC countries.

In North America, the production of specialty breads, high fiber breads and hamburger buns has increased the demand for gluten supplements. At the same time, gluten manufacturing has not been a high profit industry due to lack of high protein flour fractions (clears), low yields of gluten from clears flour and especially whole wheat, and problems with effluent disposal due to the large volumes of water required in the gluten and starch refining.

Early research between 1959-1977, primarily in England, demonstrated that roller-milled wheat flours could be separated by air classification into a fine, high protein fraction and an intermediate-sized flour which was enriched in starch content. However, the yields of fine fraction were low unless the wheat flour was reground by an impact mill. The pin mill became the industry standard for the remilling process but has not been used commercially for hard wheats because of excess starch breakage which then diluted the protein in the fines. The process is used on soft wheat flours to manufacture a fine, starchy flour for cake mixes, and works very efficiently in preparation of field pea protein concentrate and starch.

The objective of this investigation was to develop the air classification process, which utilizes no water and produces no pollutant or by-product, as a method of preparing high protein concentrates from Canadian hard red spring wheats. The lower grades of flour, which represent about 25% of the mill streams, are the prime target for this research because of their high protein contents but poor handling properties which reduce their economic value. However, the preliminary studies showed that the middlings flours process very readily in the air classifier and offer additional applications of the process. Thus, fine grinding and air classification have the potential for giving the flour miller greater control in the management of protein and starch in the wheat flour streams.

2. EQUIPMENT USED

The flours used in the present study were obtained from two commercial flour mills which normally temper the wheats to 16.0% moisture for 8-10 hr before roller milling. Pin milling was conducted on an Alpine 63 laboratory pin mill and on the commercial-sized Alpine Contraplex 250 CW pin mill (Alpine AG, Augsburg, FRG). In one experiment, the efficiency of the pin mill was compared with an attrition mill in which the principal form of grinding was by particle-to-particle attrition rather than the impact of the pin mill. The attrition mill was a commercial Hurricane Pulverizer-Classifer Vertical

Attrition Mill, Model 724/75 HP (C-E Raymond-A Division of Combustion Engineering, Inc., Chicago, IL).

The roller-, pin- and attrition- milled flours were air classified using an Alpine 132MP air classifier set at a rotor speed of 11,000 rpm into fine (less dense) and coarse (more dense) fractions. Each pass through the classifier yields only two fractions, the cut point between fine and coarse fractions depends on the vane setting in the classifier chamber. The practice was to classify at a fine setting, i.e. VS 6 or 12, and collecting the fines but passing the coarse through the mill at a wider setting, VS16, etc., until nearly all the flour had passed through the fine cut at VS34.

Scanning electron microscopy was done on a stereoscan 150EM (Cambridge Instruments, Ltd., Cambridge, UK) at an accelerating potential of 10KV. The particle sizes of the flours were initially measured on a Kontron IBAS I microcomputer and array processor after suspending the flour particles in oil and photography on a light microscope. Later, a Bioquant Image Analysis System was obtained for more precise measurements of the very fine air classified fractions (Figure 1).

3. SELECTION OF FLOUR STREAMS FROM FLOUR MILL A

This flour mill processed only hard red spring (HRS) wheats and, at the time of sampling, was producing about 75.5% of flour, the remainder being by-products - bran, shorts and germ. Considering only the flour streams (basic total flour yield = 100%), the coarse break flours constituted 25%, reduction flours 67% and various low-grade sizing and tailings 8% of the total flour production. The greatest economic return depended on the maximum production of middlings or reduction flours which are processed into patent flours for household and bakery applications. The break flours are substantially higher in protein but also contain a high proportion of cell wall material (crude fiber and ash) which have less desirable physical dough properties, and thus are marketed for less than half the wholesale price of patent flour. Industrial uses such as in pet food manufacture or gluten extraction are common for these outer endosperm break flours.

It was possible to identify 27 flour streams in the flour mill and these were sampled and analyzed for protein and ash contents (Table 1). The fifth break flour (5BK) had the highest protein content, 20.75%, as well as a high ash level which indicated an origin from outer endosperm, and first middlings coarse (IMC) had the lowest protein and ash contents, reflecting its origin from the center endosperm. It appeared that if 5BK and IMC could be air classified successfully, then it should be possible to process the other break and reduction flours without difficulty.

For phase II of the present investigation, large samples of the major streams of break flours (3BK, 3BKc, 4BK, 4BKc, 5BK, BD-1), which have the highest protein contents but lowest economic value, were collected and placed in cold storage. These streams in total represent about 10.5% of the total flour and averaged 21% protein, dry basis.

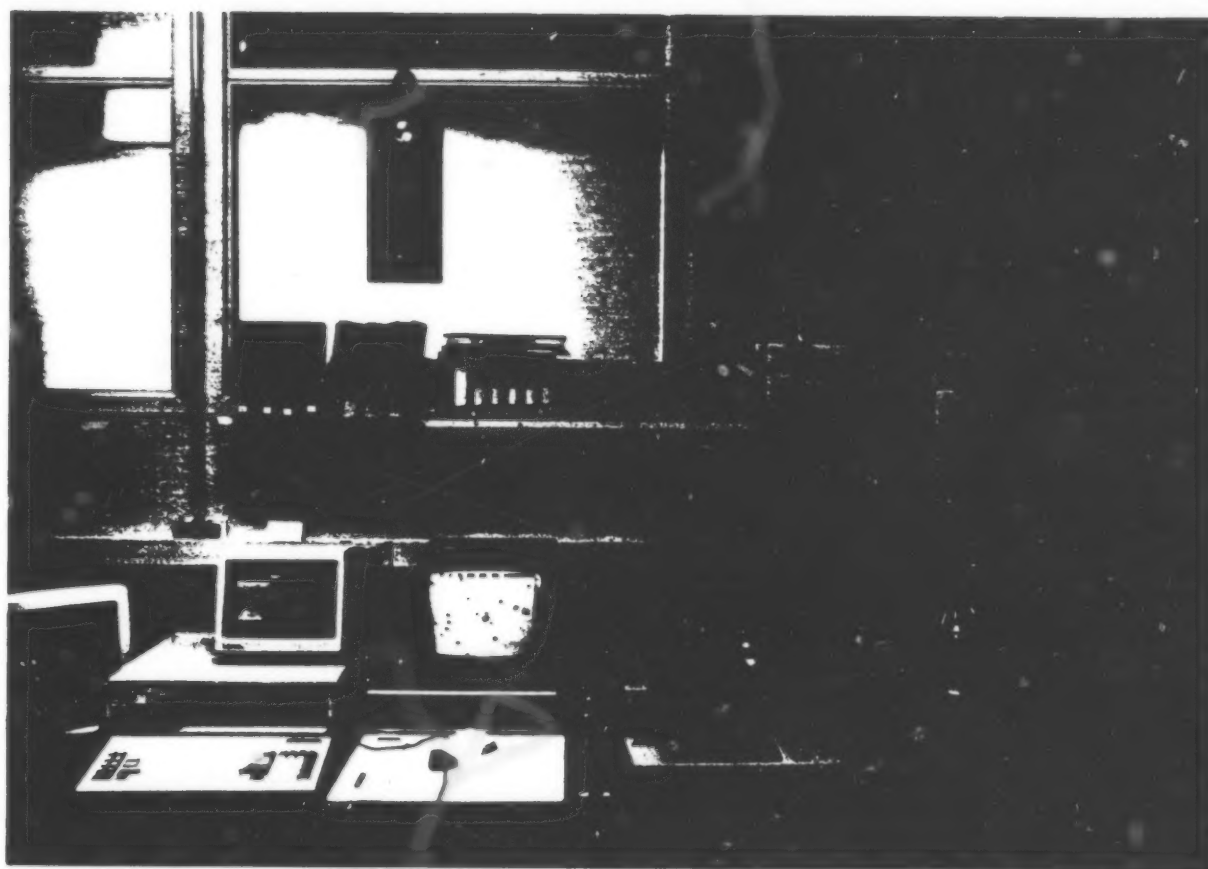


Figure 1. The Bioquant System IV image analyzer showing the Datatron computer with video display, Bioquant image processor and graphics monitor and video camera mounted on a Carl Zeiss Jena microscope.

Table 1

Production rates and proximate constituents in flour streams from the Flour Mill A in %, 14.0% moisture basis.

Milling system	Mill stream	Designation	Production rate %	Flour moisture	Flour protein	Flour ash
Break	Pre-Break	PR-BK	0.7	15.1	18.30	0.70
	1st Break	1BK	2.6	15.0	16.15	0.49
	2nd Break	2BK	7.5	14.7	16.60	0.41
	3rd Break	3BK	4.1	14.2	19.20	0.51
	4th Break	4BK	1.9	14.7	20.40	0.74
	5th Break	5BK	2.1	13.7	20.75	0.84
	1 & 2 Break Cuts	1&2BKc	2.5	15.0	16.35	0.42
	3rd Break Cuts	3BKc	0.5	14.7	18.00	0.69
	4th Break Cuts	4BKc	0.6	12.7	17.25	1.00
	Break Duster	BD	1.1	13.8	19.90	1.16
	Feed Section	FS	0.1	13.3	22.85	1.53
Sizing	1st Sizing	1S	0.4	13.8	15.60	0.50
	2&3 Sizings	2&3S	0.7	14.2	15.90	0.62
Tailings	Quality	Q	1.0	12.8	14.40	0.72
	1st Tailings	1T	0.8	13.0	15.00	0.75
	2nd Tailings	2T	0.7	12.6	13.65	0.81
	Filter Dust	FD	5.8	13.0	15.30	0.62
Reduction	Farina	F	6.3	14.3	11.45	0.33
	1st Middlings Coarse	1MC	19.5	13.5	12.50	0.37
	1st Middlings Medium	1MM	9.3	13.9	13.00	0.36
	1st Middlings Fine	1MF	0.3	13.7	14.25	0.50
	2nd Middlings	2M	18.2	13.9	12.85	0.40
	3rd Middlings	3M	5.5	13.2	13.60	0.46
	4th Middlings	4M	2.8	12.6	13.00	0.48
	5th Middlings	5M	2.5	12.7	12.80	0.52
	6th Middlings	6M	1.4	12.3	13.80	0.88
	Low Grade	LG	1.2	11.9	14.90	1.32

Table 2

Distribution of flour particle size for roller-, pin- and attrition-milled 5BK and 1MC flours, % of total flour volume

Particle diameter (μm)	Roller Mill		Pin Mill (2X)		Attrition Mill	
	5BK (%)	1MC (%)	5BK (%)	1MC (%)	5BK (%)	1MC (%)
0-15	0	0	21	17	28	39
16-30	3	3	52	56	62	56
31-45	7	4	22	22	10	5
46-60	12	5	2	5	0	0
61-75	17	8	3	0	0	0
76-90	17	11	0	0	0	0
91-105	14	11	0	0	0	0
>105	30	58	0	0	0	0

The image analysis system converted the areas of the flour particles to flour volumes to show that roller-milled flours were primarily over 75 μm diameter particle size (Table 2). Two passes through the pin mill reduced most of the particles to less than 45 μm diameter. Attrition milling was most effective in reduction of the roller-milled flour to less than 30 μm diameter. The largest starch granules would have diameters of about 30 μm and so further reduction in particle size should not be required, and would probably result in only more starch damage.

4. STARCH DAMAGE

Early investigators concluded that the regrinding of HRS wheat flours caused excessive starch granule breakage, referred to as 'starch damage', and this was undesirable in bread-making. Recently, scientists at the Grain Research Laboratory, Winnipeg demonstrated that a controlled increase in starch damage of Canadian HRS wheat caused a favorable increase in water absorption and released more glucose from starch to support yeast metabolism during dough formation (Dexter et al., 1985).

Methods of measuring starch damage are based on the greater susceptibility of broken starch granules to enzymatic hydrolysis with alpha-amylase where the intact granule is relatively resistant. Because granules will break in a variety of ways, the results of assays are only approximations. Our analytical procedures showed that the 1MC household flour had 15.7% starch damage and the first pin milling increased the value by 60%, but the next pass through the mill increased the second value by only 20% (Table 3). It was concluded that Flour Mill A was overmilling to optimize starch damage for bread-making and that values greater than 20% would be excessive.

The data for starch damage of 5BK flour was surprising and very favorable (Table 3). The starch damage was only about 11% after roller milling and two passes through the pin mill did not increase the value above 20%. As discussed in more detail later, the attrition mill caused less starch damage than pin milling in which total granule breakage was more common (Figure 2).

Table 3

Starch damage during roller, pin and attrition milling of fifth break and first middling flours (in %, 14.0% moisture basis).

Milling Process	Fifth Break	First Middlings
Roller Milled	10.9±0.2	15.7±0.1
Pin Milled		
Single Pass (1X)	16.0±0.2	25.6±0.3
Double Pass (2X)	20.2±0.2	30.5±0.4
Attrition Milled		
Coarse Setting	13.1±0.4	22.7±0.1
Fine Setting	18.3±0.4	27.1±0.0

We observed that pin milling caused considerable shattering and cracking of starch grains with radial fissures appearing in many of the larger granules. Small starch granules appeared resistant to damage. SEM-micrographs of attrition-milled flours showed a different pattern of starch damage (Figure 2). Damaged granules tended to be intact but exhibited extensive surface abrasions, deep pitting and exfoliation of the granule surface. The implications of the differences in type of starch damage for pin- and attrition-milled flours has not been evaluated.

5. OPTIMIZED AIR-CLASSIFICATION CUTS

The pin- and attrition-milled 5BK and 1MC flours were passed through an Alpine Mikroplex 132 MP spiral air classifier at five progressively-wider vane settings to give six fractions of increasing particle size. Each flour was initially classified at a narrow vane of 12 to separate the finest flour particles (Table 4). The coarse residue was reclassified at vane setting 16, and then at 20, 26 and 34, so that the sum of all cuts plus the >34 coarse residue constituted the whole flour.

For the attrition-milled 5BK and 1MC flours, the VS12 cut separated a high protein fraction (HPF) containing 30.7% protein that constituted a positive protein shift of 15.7% relative to the parent 5BK flour (Table 4). This fraction was also depleted in starch but contained 2.0% ash and 4.0% lipid. Since the coarse fraction at VS34 also exhibited a positive protein shift, the optimum air classifier cuts for 5B flour were established at VS12 and VS34 (Table 5). The HPF at VS12 could serve as a replacement for gluten supplements in weak gluten doughs and the second HPF at VS34 with low ash but uniform, intermediate

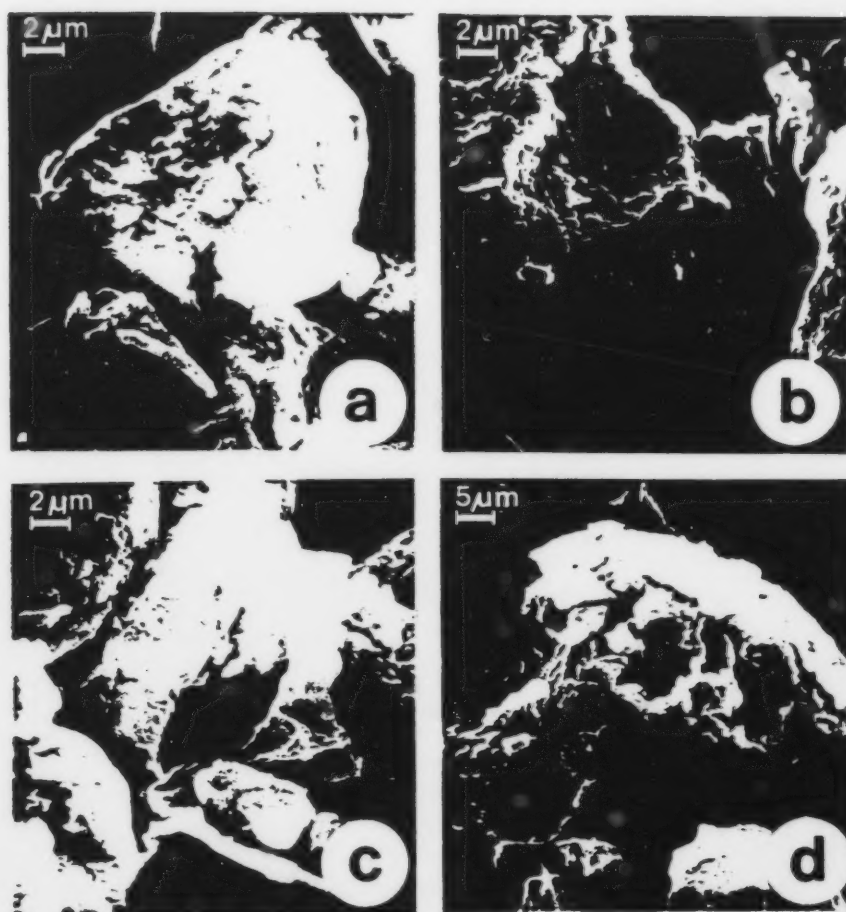


Figure 2. SEM-micrograph of reduction flour after attrition milling: (a) Magnification X 2716, (b) magnification X 2716, (c) magnification X 2716, (d) magnification X 1086.

Table 4

Composition of consecutive air-classification cuts on two attrition-milled flours in %, 14% mb^a

Vane Setting	Fraction Yield	Fraction Protein	Composition Starch	Ash	Protein Shift
Fifth Break Flour					
Flour	100	19.8	58.6	1.1	-
12	28	30.7	41.3	2.0	15.7
16	13	17.5	56.0	1.0	-1.4
20	5	14.5	66.0	0.8	-1.3
26	22	11.8	68.5	0.5	-9.4
34	22	14.3	69.4	0.5	-6.1
>34	10	24.8	58.2	0.5	2.6
First Middling Flour					
Flour	100	12.1	71.0	0.4	-
12	34	21.6	55.8	0.6	26.7
16	10	10.7	61.7	0.4	-1.1
20	4	8.4	75.8	0.4	-1.3
26	24	5.6	77.7	0.3	-13.1
34	20	6.3	79.0	0.3	-9.3
>34	8	9.3	72.9	0.3	-1.9

^a Moisture basis.

particle size could be used to upgrade low protein patent flours intended for household use. The medium protein fraction (MPF) could be blended off into baker's patent flour due to its relative low ash level. Thus, there was potential for utilizing all products from the air-classified 5BK flour as added-value protein supplements or blending flours.

An IMC flour represents one of the most valuable products from a HRS mill and would not likely be value added through further processing by fractionation on the air classifier. However, it was of interest to determine the potential degree of protein displacement in this flour from the center of

Table 5

Projected yield and composition of fractions from two-stage classification of attrition-milled flours in %, 14% mb

Vane Setting	Fraction Yield	Fraction Composition				Designation ^a
		Protein	Starch	Ash	Lipid	
Fifth Break Flour						
12 fines	28	30.7	41.3	2.0	4.0	HPF/5BK
34 fines	62	13.9	66.0	0.6	1.6	MPF/5BK
34 coarse	10	24.8	58.2	0.5	1.4	HPF/5BK
First Middling Flour						
12 fines	28	21.6	55.8	0.6	1.1	HPF/1MC
20 fines	14	10.0	66.0	0.4	0.7	MPF/1MC
20 coarse	52	6.4	77.4	0.3	0.4	LPF/1MC

^a HPF, MPF and LPF = high, medium and low protein fractions.

the kernel whereas 5BK originated from the outer endosperm. The degree of protein shift of 26.7% at VS12 was 70% greater than was obtained in 5BK (Table 4) and was comparable to the protein shift in soft wheats (Gracza, 1960). In addition, there were low protein fractions obtained at VS26 and VS34 that contained about 78.5% starch (91.3% starch on a dry basis). Due to the high proportion of these fractions, 52% in the optimized system proposed in Table 5, it is unlikely that the products of air-classified 1MC could be marketed economically relative to the cost of the initial flour.

6. BAKING QUALITY OF HPF AND MPF

Five market classes of flour were supplemented with an additional two percentage units of protein from gluten, HPF/5BK and HPF/1MC in bread dough formulations containing 15 ppm bromate. There were wide differences in positive responses among the five flours but, on average, HPF/5BK gave comparable increases in loaf volume to those obtained with vital gluten (Table 6). The results with HPF/1MC indicated a poorer response in the lower protein base flours.

Nowakowski et al. (1987) also determined the effects of blending the MPF from 5BK flour into patent and bakers' patent flours. The replacement of up to 9% MPF in HRS patent flour had no adverse effects on any bread characteristic. For bakers' patent flour, 7% replacement had no visible effects on the straight dough breads (Table 7). At higher levels of replacement, MPF reduced loaf volumes by about 5% in 'no bromate' formulations but the effect was minimal when 15 ppm bromate was added.

Table 6

Increases in loaf volume after supplementation with two percentage units of protein from gluten and HPF in %

Market Class of flour	Gluten	HPF/5BK	HPF/1MC
Soft Wheat	9.2	6.7	3.3
Prairie Spring	8.3	11.0	4.8
HRS Patent	12.5	9.6	5.1
HRS Bakers'	4.0	6.1	7.4
Triticale	11.9	15.2	15.2
Average	9.2	9.7	7.2

Table 7

Influence of MPF from air-classified 5BK flour on bread volume of bakers' patent flour

Flour Blend with MPF/5BK	Protein Content (%, 14%mb)	Volume Change in %	
		0 Bromate	15 ppm Bromate
Control	13.7	0.0	5.4
+ 7.0%	13.7	0.0	6.7
+11.0%	13.7	-4.9	2.4
+17.5%	13.7	-5.5	-2.4

7. CONCLUSIONS RE 5BK AND 1MC FLOURS

While protein shifts of over 25% are common during air classification of remilled soft wheat flours, the separation efficiency of protein into the fine fraction of air-classified hard wheat flours has usually ranged from 5-10%. The recent trend to higher starch damage in bread wheat flours may permit more intensive milling of hard wheats to increase the degree of reduction to achieve greater separation efficiency. Twice pin-milled and attrition-milled HRS break flours provided HPF with over 30% protein at protein shifts of nearly 16%. These HPF from HRS wheats appeared to be satisfactory replacements for vital gluten in bread formulations and the by-product MPF could be value-added by blending off into patent streams. These studies demonstrate the need for further research on mechanisms for regrinding hard wheat flours with less starch damage so that more efficient separations can be achieved with a single cut on the air classifier.

8. EVALUATION OF SIX BREAK FLOURS

The chemical compositions of the six break flours from Flour Mill A are shown in Table 8. Based on a new procedure for starch analysis and complete extraction of lipid, the analyses account for 94.3-96.7% of the dry matter; simple sugars and phytin would account for the remainder. All of these break flours were rich sources of protein despite their low market value.

Table 8

Proportion of total flour and composition of high protein break flour streams in a hard wheat mill in percent, dry basis

Flour Stream	Proportion	Moisture	Protein	Starch	Ash	Fat	Total
3rd Break (3BK)	4.1	9.7	20.8	73.1	0.75	2.0	96.7
3rd Break cuts (3BKc)	0.5	9.6	19.3	73.8	0.75	1.5	95.4
4th Break (4BK)	1.9	8.9	22.2	69.0	1.07	2.4	94.7
4th Break cuts (4BKc)	0.6	8.9	19.6	72.0	1.35	2.5	95.5
5th Break (5BK)	2.1	9.0	23.1	68.7	1.32	2.9	96.0
Break duster (BD)	1.2	9.3	21.0	68.1	1.70	3.5	94.3
Blend	10.4	9.4	21.4	70.4	1.06	2.5	95.4

The particle size distributions of the pin-milled break flours were determined on the Bioquant Image Analyzer, as well as those of the seven air classified fractions. The distributions for the original flour and each cut were different, as shown for 3BK and 5BK in Figures 3 and 4. Chemical analysis of each fraction demonstrated a great diversity of yield and composition for the various cuts (Table 9). For example, 3BK and 3BKc gave high yields of fines (6F) containing 35% protein while BD gave a high yield of 27% protein fines at this cut. As expected, 5BK was the most difficult break flour to process into protein and starch fractions.

The six flours were blended in the same proportions as their yields in the flour mill (Table 8) and the results on pin milling (2X) and air classification were very satisfactory (Table 9). The 18.4% yield of 6F at a protein content of 34.5% and starch content of 48.4%, dry basis, was as good as the best individual fraction. However, the yields of starchy coarse fractions (26F and 34F), and their compositions, were average for the six break flours.

Another way of comparing the six break flours and their blend, and the six flour mean, was to average the compositions of the fractions at the cut point indicated for optimum protein and starch shifts. This data is summarized in Table 10. Note that only a single cut is proposed here, in part because it provides for easier comparison of the efficiency of the system and also because the single cut may provide the best products for utilization in the mill. This summary table shows that the greatest protein shift, 20.2% was obtained in 3 BKc at VS20 and the best starch shift in 3BK at VS20 (-8.6%) and the Blend at VS20 (-8.3%).

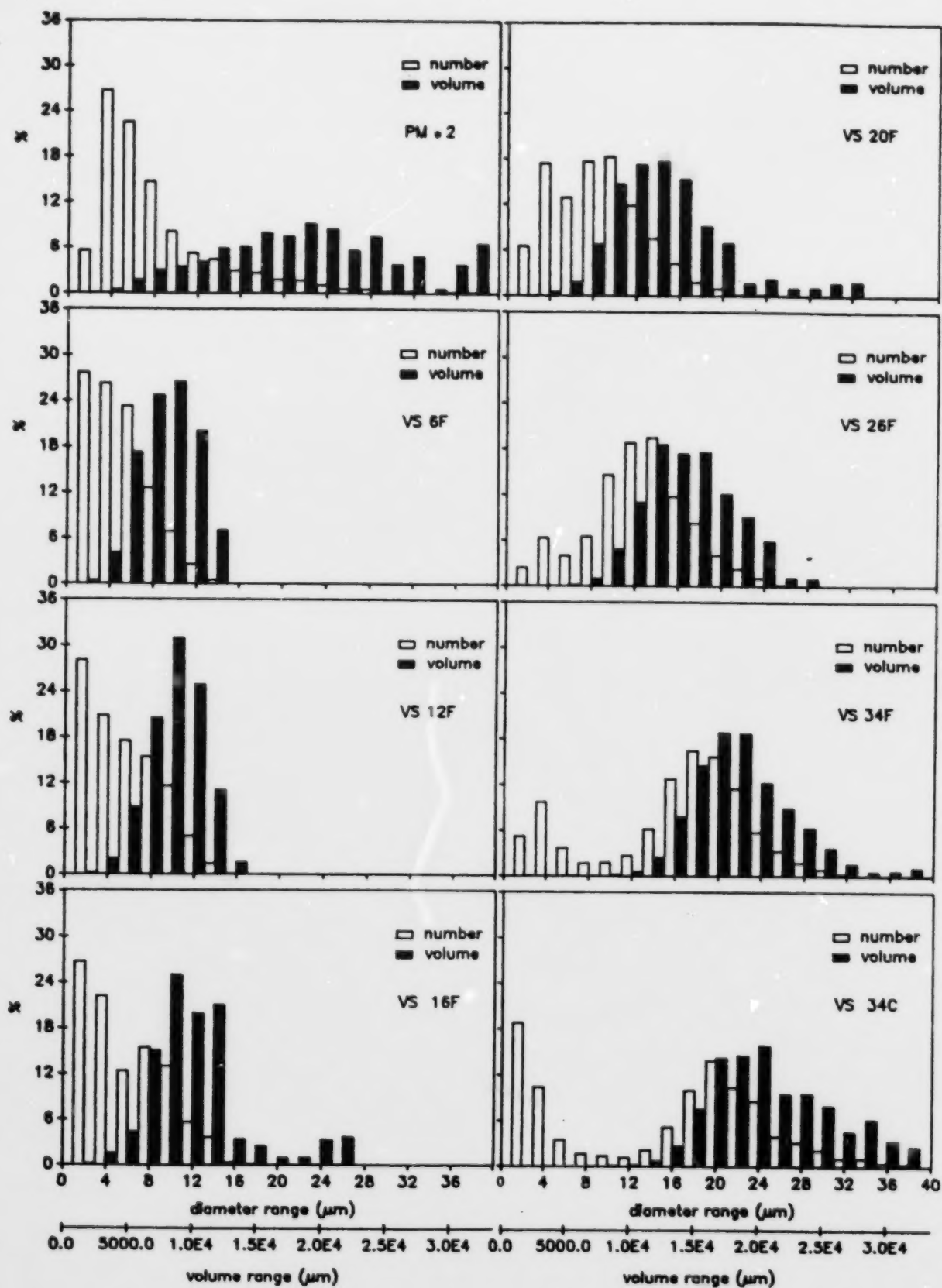


Figure 3. Number (open bars) and volume (closed bars) of flour particles within particle diameter classes in third break (3BK) flour and six progressive cuts on the air classifier.

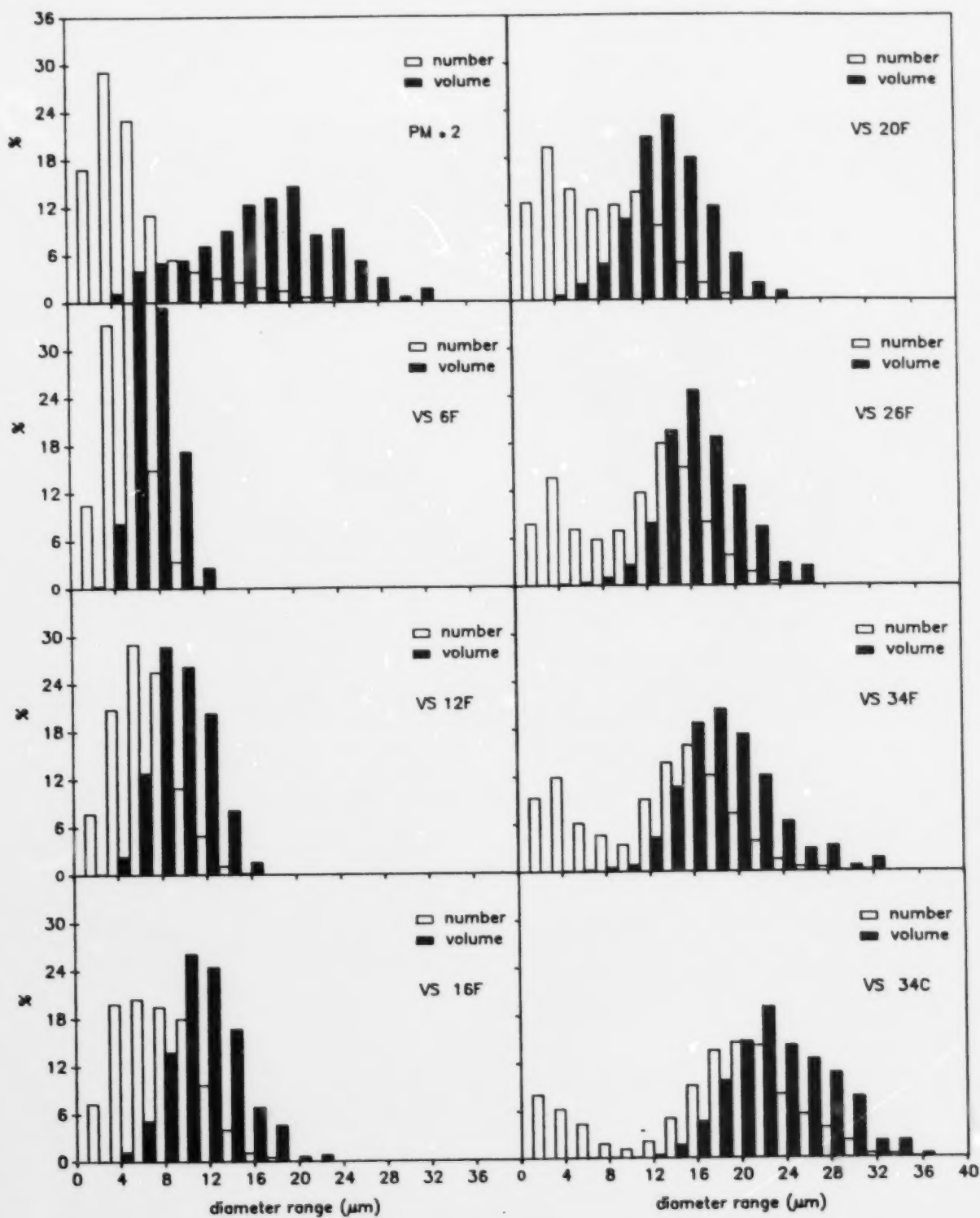


Figure 4. Number (open bars) and volume (closed bars) of flour particles within particle diameter classes in fifth break (5BK) flour and six progressive cuts on the air classifier.

Table 9

Yield and composition of fine fractions obtained by air classification of twice pin-milled break flours at six progressively-wider vane settings (% dry basis)

Flour stream	Para-meter	Fines obtained at progressively-wider vane settings							Total
		6F	12F	16F	20F	26F	34F	34C	
3BK	Yield	18.0	8.6	3.3	2.1	8.3	35.1	24.8	100
	Protein	35.9	29.1	27.7	26.5	23.1	14.5	14.8	21.1
	Starch	47.9	58.9	63.1	64.8	71.7	84.4	82.8	73.1
	Ash	1.89	1.13	0.81	0.72	0.53	0.37	0.34	0.74
	Fat	3.7	2.6	2.4	2.3	1.8	1.1	1.0	1.8
3BKc	Yield	18.5	6.4	4.4	2.7	16.6	34.9	16.5	100
	Protein	34.5	30.0	25.1	24.7	19.1	11.6	13.0	19.4
	Starch	53.4	61.3	65.6	67.1	73.9	86.2	80.1	74.1
	Ash	2.08	1.48	0.92	0.84	0.45	0.31	0.34	0.78
	Fat	3.1	2.5	1.9	1.8	1.3	0.8	0.8	1.5
4BK	Yield	17.9	6.6	4.0	8.3	11.4	30.9	20.9	100
	Protein	36.0	32.3	28.6	22.4	21.8	14.6	18.1	22.4
	Starch	46.8	53.2	59.3	70.4	72.1	80.2	74.5	68.7
	Ash	2.78	2.06	1.30	0.72	0.61	0.41	0.38	1.02
	Fat	4.4	3.6	2.9	2.0	1.9	1.1	1.2	2.1
4BKc	Yield	19.2	8.7	5.0	4.6	7.0	28.1	27.4	100
	Protein	33.0	27.3	25.2	23.4	19.5	12.9	13.4	19.7
	Starch	51.1	60.0	65.9	67.8	74.6	81.3	81.2	71.8
	Ash	3.66	2.31	1.48	1.12	0.77	0.51	0.50	1.36
	Fat	4.6	3.6	2.9	2.6	2.1	1.4	1.2	2.3
5BK	Yield	11.1	14.2	12.5	11.7	14.8	21.6	14.1	100
	Protein	37.3	31.7	26.2	20.4	16.7	15.1	24.4	23.5
	Starch	45.3	53.5	64.2	73.3	79.7	82.4	66.3	68.1
	Ash	3.77	2.82	1.41	0.78	0.54	0.46	0.43	1.33
	Fat	5.52	4.39	3.19	2.32	1.85	1.52	1.58	2.73
BD	Yield	29.0	6.1	6.9	8.8	13.2	19.0	17.1	100.1
	Protein	26.9	29.7	25.9	21.0	15.7	13.2	19.5	21.1
	Starch	58.2	51.8	58.7	65.8	75.6	81.4	70.9	67.4
	Ash	2.86	3.56	2.51	1.30	0.77	0.53	0.62	1.64
	Fat	4.67	5.27	4.48	3.32	2.39	1.81	1.87	3.25
Blend	Yield	18.4	8.3	4.9	6.7	11.2	25.2	25.3	100
	Protein	34.5	29.6	26.6	23.5	19.0	13.9	17.2	21.7
	Starch	48.4	55.5	62.9	67.7	75.3	82.2	76.4	69.6
	Ash	2.96	1.93	1.14	0.78	0.56	0.43	0.39	1.08
	Fat	4.73	3.75	3.05	2.56	1.79	1.31	1.48	2.41

Table 10

Yield and composition of fine and coarse fractions from air classification of twice pin-milled break flours at optimum vane settings based on degree of protein shift (% dry basis)

Flour/Vane Setting	Fraction	Yield	Protein	Starch	Ash	Fat	Degree of Shift	
							Protein	Starch
3BK 20	Fine	32.0	32.6	53.5	1.50	3.2	18.2	-8.6
	Coarse	68.0	15.7	82.3	0.38	1.2	-16.9	8.6
3BKc 20	Fine	32.0	31.5	57.8	1.70	2.7	20.2	-6.9
	Coarse	68.0	13.8	81.7	0.35	1.0	-19.5	7.3
4BK 16	Fine	28.5	34.1	50.0	2.41	4.0	15.3	-7.8
	Coarse	71.5	17.7	76.1	0.47	1.4	-14.6	7.4
4BKc 20	Fine	37.5	29.5	57.2	2.74	3.9	18.9	-7.7
	Coarse	62.5	13.9	80.5	0.53	1.4	-18.3	7.4
5BK 16	Fine	37.8	31.5	54.6	2.63	4.3	13.8	-7.8
	Coarse	62.2	18.6	76.4	0.53	1.8	-12.2	6.9
BD 20	Fine	50.8	26.1	58.8	2.63	4.5	12.3	-6.9
	Coarse	49.2	16.1	76.2	0.63	2.0	-11.6	5.8
Mean	Fine	34.9	31.3	54.5	2.13	3.7	15.8	7.8
	Coarse	65.1	16.5	79.3	0.46	1.4	-15.6	-7.6
Blend 20	Fine	38.3	30.5	55.2	2.12	3.9	16.3	-8.3
	Coarse	61.7	16.2	78.6	0.44	1.5	-15.1	7.6

9. CONCLUSIONS RE SIX BREAK FLOURS

Regrinding of the break flours by two passes through the pin mill is satisfactory for an effective separation of protein in break flours, i.e. a 15-20% shift of protein into the fine fraction. However, the fines are seriously contaminated by starch, i.e. 50-60%, which represents the small starch granules (unavoidable) and broken starch. The latter appeared to be substantially reduced in the 5B flour (41%) but not in 1M flour after regrinding in the attrition mill. Other milling systems need to be evaluated which operate on the abrasion principle.

The experiments with the six break flours show that individual flours yield unique fractions which may have value in the management of protein in the mill. If the objective is to reprocess all low-grade break flours, then a blended break flour can be processed as efficiently as processing each separately at their most efficient cut point.

Previous investigators have found that the presence of flour agglomerates in the pin-milled flours made it necessary to air classify twice, once to separate the fines and the second to separate the starchy fraction from the agglomerates. By more complete reduction in flour particle size via two pin millings or attrition milling, the yield and protein level of 34C was reduced sufficiently to render this step uneconomical in many cases.

10. WORK PLAN FOR FLOUR MILL B FLOURS

The major flour streams from the Flour Mill B were collected and sampled for chemical analysis. The bulk of the material (30 kg) was air-dried from the original 13.0-15.5% moisture to approximately 10.5% on the day of pin-milling (Table 11). Two passes through the pin mill reduced the moisture content of the flours to 4.7-5.5% at which level the moisture remained constant (5.0-6.0%) throughout the several air classification cuts.

Pin milling was conducted on an Alpine 250 CW pin mill at feed gate openings of 15 mm for the first pass and 20 mm for the second pass. The pin-milled flours were then fractionated into fine and coarse fractions on an Alpine 132 MP air classifier at a rotor speed of 11,000 rpm. All flours were air classified at the narrow vane setting of 6 (VS6), after which the coarse fraction was reclassified at a wider vane setting of 12. The coarse fraction from VS12 was again classified as VS16, etc. so that the sum of VS6, 12, 16, 20, 26 and 34 fine and coarse constituted the whole of each flour. The feed gate opening of 7 mm was used in each case.

Particle size analysis of each fraction from the air classifier was conducted by dispersing the particles in ethanol on a glass slide, drying the dispersed flour and visualizing the particles on a Leitz microscope at 400 magnification. A video camera was mounted on the microscope and the image displayed on a monochrome monitor for computerized image analysis using the Bioquant digitizer and software.

11. COMPOSITION OF FLOUR MILL B FLOURS

The proportions of break flours and reduction flours produced in normal milling practice by the Flour Mill B are only an approximation since the actual yields are commercially confidential (Table 11). Compared to Flour Mill A operation, the B mill markets a wider range of flour qualities, with less emphasis on yield of patent (1M and 2M) flours. Thus, there is greater production of break flours at Mill B but the staff indicate that disposal of the break flours is less of a problem than has been experienced by Flour Mill A.

Table 11

Production rates, processing conditions and composition of Flour Mill B flours

Mill streams	Proportion of total flour ^a	Feed rate		Moisture content, %			Protein content, % ^b	
		kg/min		As	Air	Pin	As	Dry
		First pass	Second pass	rec- eived	dried	milled (2x)	is	basis
<u>Break flours</u>								
1 Bk	18.5	0.8	0.6	15.5	10.3	5.1	14.3	17.0
2 Bk	36.0	0.9	0.7	15.5	10.6	5.3	14.8	17.6
3 Bk	25.0	0.7	0.7	14.9	10.7	5.0	17.2	20.2
4 Bk	14.0	1.1	1.0	14.2	10.3	4.7	19.7	22.9
5 Bk	6.5	1.0	1.0	14.2	9.6	4.7	20.1	23.3
Bk blend ^c 100		1.0	0.7	14.9	10.4	4.7	16.0	18.8
<u>Reduction flours</u>								
1 M	41.5	0.5	0.5	14.4	10.8	5.3	12.1	14.1
2 M	41.5	0.6	0.6	13.8	10.9	5.2	11.4	13.0
3 M	10.0	0.6	0.6	13.5	10.7	5.5	11.6	13.7
4 M	7.0	0.6	0.5	13.0	9.3	5.5	11.3	13.2
M blend ^c 100		0.6	0.6	14.0	10.8	5.1	11.9	13.9

^a Break flours represent about 25% of the total flour production, and reduction or middling flours are the major flour grades at a production rate of 75%.

^b Kjeldahl N x 5.7.

^c Blended in the above proportions.

12. PROCESSING THE FLOUR MILL B FLOURS

The feed rates through the pin mill are adjusted to maintain rotor speeds, and the low-protein reduction flours showed the greatest resistance to regrinding (Table 11). The high protein 4 Bk and 5 Bk flours could be reground at twice the rate of 1 M flour. Apparently the cells of the central endosperm, which are packed with starch granules, provide the greatest resistance to impact grinding.

A previous study showed that air classification was most effective at flour moisture contents of less than 7%. But there was concern that hot air drying might decrease protein functionality through thermal denaturation of the proteins. The present samples were, therefore, air dried, over a 5-day period, to about 10.5% moisture (Table 11). Two passes through the pin mill decreased the flour moisture to about 5%.

The reduction flours varied between 13.0% and 14.1% protein, dry basis, while those of the break system increased progressively from 17.0% for 1 Bk to 23.3% for 5 Bk (Table 11). The proportional blends contained 18.8% and 13.9% protein for the reduction and break flours, respectively. It should be noted that the protein level of 14.1% for 1 M was high for this mill stream.

The data on other chemical constituents of the nine parent flours and two blends has been incorporated into Tables 12 and 13 under the last column designated "Original". Note that starch content decreased from 77.6% for 1 Bk to 68.0% in 5 Bk, with an average of 74.5% for the Bk blend. On the other hand, starch levels increased from 81.3% in 1 M to 84.9% in 4 M. Ash and fat levels were positively correlated with protein content, the values almost doubling between 1 Bk and 5 Bk.

Air classification of each parent flour, after pin milling, was done at the fine opening, vane setting 6, and the coarse fraction reclassified at the next setting, 12, etc., until about 15% of the flour remained as a coarse fraction, 34 C (Tables 12 and 13). The finest cuts of break flours contained 30.6 to 35.9% protein and 51.0 to 56.3% starch. The 34F fraction has the lowest protein, 9.5 to 15.3%, and highest starch, 82.3 to 88.8%, in the break flour series. The protein shifts into the fine fractions ranged from about 21% for 1 Bk and 2 Bk to 13% for 5 Bk (Table 14). Starch shifts into coarser fractions were only 7.6 to 6.5% for this series.

The low protein, middling flours showed a protein concentration of about 25% in 6F and only 7-8% in 34F (Table 13). Starch contents in 6F were 65-70%, and increased to over 90% in 34F. The calculated protein shifts were as high as for break flours, about 22%, but starch shift was lower at 4-5% (Table 14).

These data clearly demonstrate that the air classification efficiency could be greatly improved by shifting more starch from the fine fractions, 6F and 12F, into the coarse cuts at VS26 and 34. The less efficient starch split for middlings flours may be associated with the high proportion of small starch granules in the center endosperm, as well as potentially greater starch damage. Limiting starch damage would be most helpful in improving protein and starch separation on the air classifier, and other grinding systems than the pin mill are under investigation.

The data in Tables 12 and 13 was subjected to computerized evaluation and it appeared that two cuts of the pin-milled flours would yield the optimal quantities of high protein/low protein fractions but this procedure also yielded a third intermediate fraction. Among the break flours, the first cut could be at VS6, 12 or 16, depending on the fraction, but the second air classification of the coarse material from the first cut was consistently at VS20 except for 5 Bk (Table 15). For the Bk blend (Table 15) and all middling flours (Table 16), the optimized cuts were at VS6 and VS20. Except for 5 Bk, the total yields of the two fine fractions totalled 40-45% and the final coarse fraction, 55-60%. The first fine cuts has 25-35% protein plus high ash

Table 12

Yield and composition of fine fractions and the final coarse residue of pin-milled break flours at six progressively-wider vane settings in %, dry basis

Flour stream	Parameter	6F	12F	16F	20F	26F	34F	34C	Recovered	Original
1 Bk	Yield	19.6	10.6	6.2	4.4	16.5	30.2	12.5	-	-
	Protein	30.6	22.6	19.0	16.6	10.6	9.5	13.7	16.6	17.0
	Starch	56.1	67.2	74.0	78.7	85.1	88.7	82.4	77.3	77.6
	Ash	1.42	1.02	0.78	0.67	0.45	0.38	0.60	0.73	0.70
	Fat	2.4	1.7	1.4	1.2	0.8	0.7	1.0	1.3	1.3
2 Bk	Yield	21.0	10.6	4.0	5.1	16.6	30.7	12.0	-	-
	Protein	31.6	23.2	21.9	17.5	11.5	9.7	13.8	17.4	17.6
	Starch	55.2	67.0	70.7	76.4	86.3	88.8	81.9	76.8	77.1
	Ash	1.49	1.02	0.93	0.74	0.51	0.41	0.57	0.77	0.75
	Fat	2.4	1.7	1.6	1.3	0.9	0.7	1.0	1.3	1.3
3 Bk	Yield	16.5	10.6	6.2	5.1	12.3	32.0	17.4	-	-
	Protein	35.9	27.2	24.7	21.7	15.3	12.2	17.2	20.2	20.2
	Starch	51.0	65.3	68.9	73.2	77.7	84.5	80.1	73.8	74.2
	Ash	1.85	1.17	1.06	0.95	0.76	0.57	0.71	0.94	0.87
	Fat	3.7	2.7	2.4	2.1	1.5	1.2	1.7	2.0	2.0
4 Bk	Yield	24.7	7.9	5.7	4.0	13.9	28.5	15.3	-	-
	Protein	32.2	30.3	26.7	23.3	17.0	14.5	21.9	22.6	22.9
	Starch	54.2	59.7	66.4	71.1	79.0	82.3	71.9	70.2	70.1
	Ash	1.82	1.65	1.25	1.20	0.93	0.80	1.13	1.23	1.21
	Fat	3.4	3.1	2.7	2.2	1.7	1.4	2.2	2.3	2.3
5 Bk	Yield	21.3	10.7	4.9	7.4	18.9	21.3	15.5	-	-
	Protein	31.6	29.5	27.2	21.6	16.5	15.3	25.1	23.1	23.3
	Starch	56.3	60.2	64.9	71.2	77.8	82.4	66.4	69.4	68.0
	Ash	1.74	1.57	1.49	1.10	0.92	0.88	1.30	1.26	1.30
	Fat	3.9	3.5	3.2	2.5	2.0	1.7	2.9	2.7	2.7
Bk Blend	Yield	19.4	12.8	6.4	4.9	12.9	25.8	18.0	-	-
	Protein	32.7	24.5	20.8	17.9	12.8	10.9	15.5	18.9	18.8
	Starch	54.3	67.0	70.2	77.9	82.1	87.3	80.4	74.9	74.5
	Ash	1.72	1.11	1.01	0.91	0.67	0.51	0.79	0.94	0.92
	Fat	3.0	2.3	1.9	1.7	1.0	1.0	1.4	1.7	1.7

Table 13

Yield and composition of fine fractions and final coarse residue of pin-milled reduction flours at six progressively-wider vane settings in %, dry basis

Flour stream	Parameter	6F	12F	16F	20F	26F	34F	34C	Recovered	Original
1M	Yield	23.0	11.1	4.3	3.0	19.9	30.0	8.6	-	-
	Protein	25.4	18.2	16.4	14.2	8.7	8.3	11.0	14.2	14.1
	Starch	66.3	76.9	80.2	84.7	88.4	89.8	87.0	81.9	81.3
	Ash	0.82	0.56	0.51	0.40	0.30	0.27	0.38	0.46	0.45
	Fat	1.8	1.2	1.0	0.9	0.7	0.6	0.8	1.0	1.1
2M	Yield	19.0	13.5	4.4	3.8	14.8	30.7	13.8	-	-
	Protein	25.1	16.7	14.7	13.6	8.3	7.4	10.0	13.1	13.0
	Starch	68.9	78.7	82.8	84.0	87.1	91.3	87.5	83.5	83.1
	Ash	1.00	0.68	0.50	0.49	0.31	0.26	0.36	0.50	0.45
	Fat	1.8	1.2	1.0	1.0	0.6	0.5	0.7	0.9	0.9
3M	Yield	18.1	8.5	9.3	4.0	19.6	28.2	12.4	-	-
	Protein	26.5	18.3	14.4	12.6	8.3	7.7	11.9	13.5	13.7
	Starch	66.5	75.2	81.9	85.6	90.1	91.4	84.7	83.3	83.2
	Ash	1.01	0.62	0.40	0.36	0.26	0.21	0.37	0.44	0.42
	Fat	1.9	1.3	1.0	0.9	0.6	0.6	0.8	1.0	0.9
4M	Yield	17.8	10.0	6.1	3.9	18.1	32.0	12.1	-	-
	Protein	25.6	17.6	14.0	12.7	8.1	7.1	10.3	12.7	13.2
	Starch	68.7	78.9	83.2	85.0	90.1	92.4	85.5	84.7	84.9
	Ash	0.99	0.56	0.43	0.33	0.27	0.21	0.30	0.42	0.39
	Fat	1.7	1.3	0.9	0.8	0.5	0.5	0.7	0.9	0.9
M Blend	Yield	19.1	11.8	6.8	3.6	18.2	30.2	10.3	-	-
	Protein	27.0	18.3	15.0	13.2	8.3	7.3	10.4	13.6	13.9
	Starch	64.5	75.9	81.1	84.3	90.6	91.4	87.8	83.0	82.6
	Ash	0.92	0.55	0.43	0.41	0.26	0.22	0.34	0.43	0.42
	Fat	2.0	1.5	1.1	1.0	0.6	0.5	0.8	1.0	1.0

Table 14

Protein and starch shift into fine fractions and final coarse residue of break and reduction flours obtained at six progressively-wider vane settings in %, dry basis

VS	1Bk	2Bk	3Bk	4Bk	5Bk	Bk Blend	1M	2M	3M	4M	M Blend
Protein shift											
6	15.7	16.7	12.8	10.0	7.6	14.3	18.4	17.7	16.9	16.7	18.0
12	3.5	3.4	3.7	2.6	2.8	3.9	3.2	3.8	2.9	3.3	3.7
16	0.7	1.0	1.4	0.9	0.8	0.7	0.7	0.6	0.5	0.4	0.5
20	- 0.1	0.0	0.4	0.1	- 0.5	- 0.2	0.0	0.2	- 0.3	- 0.1	- 0.2
26	- 6.2	- 5.8	- 3.0	- 3.6	- 5.5	- 4.1	- 7.6	- 5.4	- 7.7	- 7.0	- 7.3
34	-13.3	-13.8	-12.7	-10.5	- 7.3	-10.8	-12.3	-13.2	-12.4	-14.8	-14.3
>34	- 2.4	- 2.6	- 2.6	- 0.7	1.2	- 3.2	- 1.9	- 3.2	- 1.6	- 2.7	- 2.6
Ave. ^a	21.0	21.6	18.2	14.2	12.9	18.6	22.1	22.0	21.1	22.5	23.4
Starch shift											
6	- 5.4	- 6.0	- 5.2	- 5.6	- 3.7	- 5.3	- 4.2	- 3.2	- 3.6	- 3.4	- 4.2
12	- 1.4	- 1.4	- 1.3	- 1.2	- 1.2	- 1.3	- 0.6	- 0.7	- 0.8	- 0.7	- 1.0
16	- 0.3	- 0.3	- 0.4	- 0.3	- 0.2	- 0.4	- 0.1	0.0	- 0.1	- 0.1	- 0.1
20	0.1	0.0	- 0.1	0.1	0.3	0.2	0.1	0.0	0.1	0.0	0.1
26	1.6	2.0	0.6	1.8	2.7	1.3	1.7	0.7	1.6	1.1	1.8
34	4.3	4.7	4.4	5.0	4.5	4.4	3.1	3.0	2.8	2.8	3.2
>34	0.8	0.7	1.4	0.4	- 0.4	1.4	0.6	0.7	0.2	0.1	0.6
Ave. ^a	6.9	7.6	6.7	7.1	6.5	7.2	5.3	4.2	4.7	4.1	5.5

^a Average of total positive and negative shifts in protein and starch in the fine and coarse fractions, respectively.

and fat. The starch content in the fine cut was 50-60% for the break flours and 65-70% for the first middling flours. To enhance the protein content of this fraction, much more starch would need to be excluded from this fine cut. Further work will be done to characterize this starch component, by starch damage analysis, scanning electron microscopy, particle size, etc., before devising a strategy to improve the fractionation procedure.

The coarse fractions obtained at VS20 for 1,2 and 3 Bk provide low ash and low fat flours which could be blended into baker's patent flour (Table 16). This would constitute a substantial upgrading of these flours into a value-added use. The 4 Bk and 5 Bk coarse fractions increased the ash and fat contents of the Bk blend, which appeared to process as an average of the five break flours.

The coarse fraction from processing the middling flours contained a unique composition: 90% starch, 8% protein and only 0.25% ash. A major utilization study would be required to determine the most economic uses for this product.

Table 15

Yield and composition of fine and coarse fractions from air classification of break flours at optimum vane settings based on degree of protein shift, % dry basis

Flour	VS	Fraction	Yield	Protein	Starch	Ash	Fat	Degree of Shift	
								Protein	Starch
1 Bk	12	Fine	30.2	27.8	60.0	1.28	2.1	19.3	-6.9
	20	Fine	10.6	18.0	76.0	0.73	1.4	0.7	-1.8
	20	Coarse	59.2	10.7	86.4	0.45	0.8	-21.9	6.7
2 Bk	6	Fine	21.0	31.6	55.2	1.49	2.4	16.7	-6.0
	20	Fine	19.7	21.5	70.2	0.93	1.6	4.4	-1.7
	20	Coarse	59.3	11.0	86.7	0.47	0.8	-22.2	7.4
3 Bk	6	Fine	16.5	35.9	51.0	1.85	3.7	12.8	-5.2
	20	Fine	21.9	25.2	68.2	1.09	2.5	5.5	-1.9
	20	Coarse	61.7	14.2	81.9	0.65	1.4	-18.3	6.4
4 Bk	12	Fine	32.6	31.7	55.5	1.78	3.4	12.5	-6.8
	20	Fine	9.7	27.5	68.3	1.23	2.5	1.0	-0.2
	20	Coarse	57.7	17.1	78.7	0.92	1.7	-14.8	7.1
5 Bk	16	Fine	36.9	30.4	58.6	1.66	3.7	11.2	-5.1
	34	Fine	47.6	16.7	79.1	0.93	1.9	-13.4	7.5
	34	Coarse	15.5	25.1	66.4	1.30	2.9	1.2	-0.4
Bk Blend	6	Fine	19.4	32.7	54.3	1.72	3.0	14.3	-5.3
	20	Fine	24.1	22.2	70.1	0.94	2.1	4.3	-1.5
	20	Coarse	56.7	12.8	83.9	0.64	1.1	-18.2	7.2

Table 16

Yield and composition of fine and coarse fractions from air classification of reduction flours at optimum vane settings based on degree of protein shift, % dry basis

Flour	VS	Fraction	Yield	Protein	Starch	Ash	Fat	Degree of shift	
								Protein	Starch
1M	6	Fine	23.0	25.4	66.3	0.82	1.8	18.4	-4.2
	20	Fine	18.4	17.1	78.9	0.52	1.1	3.9	-0.6
	20	Coarse	58.5	8.8	88.9	0.30	0.7	-21.9	5.5
2M	6	Fine	19.0	25.1	68.9	1.00	1.8	17.5	-3.2
	20	Fine	21.7	15.7	80.5	0.61	1.1	4.5	-0.7
	20	Coarse	59.3	8.2	89.4	0.30	0.6	-21.8	4.5
3M	6	Fine	18.1	26.5	66.5	1.01	1.9	17.0	-3.6
	20	Fine	21.8	15.6	80.0	0.48	1.1	3.0	-1.0
	20	Coarse	60.2	8.8	89.6	0.26	0.6	-21.7	4.6
4M	6	Fine	17.8	25.6	68.7	1.00	1.7	16.8	-3.4
	20	Fine	20.0	15.6	81.4	0.48	1.1	3.6	-0.8
	20	Coarse	62.2	8.0	90.4	0.24	0.6	-24.5	4.0
M Blend	6	Fine	19.1	27.0	64.5	0.92	2.0	17.9	-4.2
	20	Fine	22.2	16.4	78.9	0.49	1.3	4.0	-1.2
	20	Coarse	58.7	8.2	90.5	0.25	0.6	-24.3	5.6

13. CONCLUSIONS RE FLOUR MILL B CLASSIFICATIONS

The results obtained by pin milling and air classification of the Flour Mill B streams closely parallel those of the Flour Mill A flours. The data confirm that the two fractions studied in detail previously, 5 Bk and 1M, were the most difficult break and reduction flours, respectively, to fractionate. It appeared that air classification of the individual flour streams could provide the highest separation efficiencies, i.e. 21.6% for protein and 7.6% for starch in 2 Bk flour (Table 14), but processing a blend of all fractions gave an average performance of the individual components. It appeared that an initial air classification at VS6 or 12 would provide an optimum yield of fine fraction with high protein content, but the levels were limited by the 50-65% of residual starch in these fractions. In all but one flour, the second classification at VS20 separated the starchy (80-90%) fraction from an intermediate component that was sufficiently rich in protein to have a value-added application in the flour mill.

14. BAKING QUALITY OF WHEAT PROTEIN CONCENTRATES FROM FLOUR MILL B

The quality of the high protein fractions (wheat protein concentrates) from Mill B were evaluated as supplements in high fiber breads. The fines from 1 BK, 3BK and BK Blend were tested at two levels in bread dough formulated to contain 0, 10, 20 and 25% of wheat bran (Table 17). These levels of bran increased water absorptions of the doughs progressively from 62.8 to 75.3% but decreased loaf volumes from 875 to 648 cc. The addition of 5% wheat gluten improved loaf volumes of the 0 and 10% wheat bran breads but not the 20 and 25% bran breads.

The HPF from the break flours were added to the wheat bran doughs at levels intended to increase the protein levels by 2 and 4% units compared to the 3% increase resulting from the addition of gluten at the 5% level (Table 17). The 3BK and BK Blend fines improved loaf characteristics more than 1 BK fines, the lower levels equalled the effects of gluten and their higher levels improved the bread characteristics of the 20 and 25% fiber breads as compared to gluten. Also, water absorptions were increased relative to the controls and gluten.

The 2BK, 4BK and 5BK fines were used as gluten supplements in oat bran breads where average protein levels in the breads were about 1% lower than wheat bran breads (Table 18). Water absorptions of the bread doughs increased only slightly from the additions of 10, 20 and 25% of oat bran. The supplementation with 5% gluten improved loaf volume and bread characteristics of oat bran breads to a greater degree than for wheat bran bread, especially at the higher bran levels (Table 17).

Table 17
Influence of gluten and wheat protein concentrates on bread loaf characteristics of wheat bran bread, dry basis

Level of Protein bran %	Protein content %	Water absorption %	Loaf volume cc	Specific gravity cc/g	Crumb compressibility kg/g	Loaf shape -	Crumb texture -
No Protein Supplement							
0	14.2	62.8	875	5.9	3.9	VG	VG
10	14.1	67.8	755	4.9	3.1	G	G
20	14.2	72.8	675	4.3	2.6	F	F
25	14.4	75.3	648	4.1	2.5	F	F
5% Wheat Gluten							
0	17.3	63.8	950	6.3	4.0	VG	VG
10	17.4	68.8	855	5.5	4.5	VG	VG
20	17.6	73.8	710	4.4	4.7	G	G
25	17.5	76.3	665	3.9	2.5	F	F
13.5% First Break Fines (VS6)							
0	15.5	65.8	910	6.1	4.0	VG	VG
10	16.3	70.8	825	5.3	3.4	G	G
20	16.4	75.8	690	4.2	2.7	F	F
25	16.3	78.3	655	3.9	2.4	F	F
27% First Break Fines (VS6)							
0	18.0	68.8	915	6.1	4.4	VG	VG
10	18.2	73.8	845	5.0	3.0	G	G
20	18.5	78.8	690	4.2	2.8	F	F
25	18.7	81.3	650	3.8	2.7	F	F
11.5% Third Break Fines (VS6)							
0	16.3	65.8	913	6.1	4.0	VG	VG
10	16.3	70.8	800	5.2	3.5	G	G
20	16.7	75.8	705	4.4	3.0	F	F
25	16.8	78.3	660	4.0	2.5	F	F
23% Third Break Fines (VS6)							
0	18.6	68.8	925	6.1	4.3	VG	VG
10	18.7	73.8	855	5.4	3.6	VG	VG
20	18.9	78.8	790	4.8	2.8	G	G
25	19.2	81.3	715	4.3	2.7	F	G
12.5% Break Blend (VS6)							
0	16.4	65.8	915	6.2	3.7	VG	VG
10	16.7	70.8	795	5.1	3.7	G	G
20	16.6	75.8	748	4.6	2.7	G	G
25	16.5	78.3	700	4.2	2.3	G	G
25% Break Blend (VS6)							
0	18.5	68.8	940	6.1	3.3	VG	VG
10	18.6	73.8	875	5.5	3.2	VG	VG
20	18.8	78.8	760	4.6	3.1	G	G
25	18.7	81.3	705	4.2	2.6	G	G

Table 18

Influence of gluten and wheat protein concentrates on bread loaf characteristics of oat bran bread, dry basis

Level of Protein bran %	Protein content %	Water absorption %	Loaf volume cc	Specific gravity cc/g	Crumb compressibility kg/g	Loaf shape -	Crumb texture -
No Protein Supplement							
0	13.4	62.8	855	5.7	3.5	VG	VG
10	13.4	63.8	810	5.4	3.4	G	G
20	13.3	64.8	750	4.9	3.0	G	G
25	13.3	64.3	700	4.6	3.8	F	F
5% Wheat Gluten							
0	16.8	63.8	950	6.4	4.2	VG	G
10	16.5	64.8	885	5.9	3.6	VG	VG
20	16.3	65.8	770	5.0	3.6	G	G
25	16.4	66.3	730	4.8	3.5	G	G
13% Second Break Fines (VS6)							
0	15.5	65.8	905	5.9	3.3	VG	VG
10	15.1	66.3	825	5.4	3.7	G	G
20	15.3	66.8	735	4.8	3.1	G	G
25	15.2	67.3	705	4.6	3.1	F	F
26% Second Break Fines (VS6)							
0	17.4	67.8	885	5.7	3.4	VG	VG
10	17.3	68.3	835	5.3	3.5	VG	G
20	17.2	68.8	790	5.0	3.3	G	G
25	17.0	69.3	755	4.8	3.5	G	G
13% Fourth Break Fines (VS6)							
0	15.5	65.8	855	5.6	3.7	VG	VG
10	15.4	66.3	780	5.1	3.9	G	G
20	15.4	66.8	740	4.8	3.2	G	G
25	15.3	66.8	705	4.5	3.1	F	F
26% Fourth Break Fines (VS6)							
0	17.1	67.8	905	5.8	3.3	VG	VG
10	17.4	68.3	815	5.2	3.5	G	G
20	17.2	68.8	795	5.0	3.5	G	G
25	17.4	68.8	765	4.8	3.3	G	G
13% Fifth Break Fines (VS6)							
0	14.8	65.8	865	5.7	3.3	VG	VG
10	14.9	66.3	840	5.5	3.2	VG	VG
20	15.1	66.8	780	5.0	3.0	G	G
25	14.8	66.8	745	4.8	2.8	G	G
26% Fifth Break Fines (VS6)							
0	17.0	68.8	905	5.8	3.1	VG	VG
10	17.1	68.3	860	5.5	3.6	VG	VG
20	17.0	69.3	795	5.1	3.1	G	G
25	17.0	69.3	750	4.7	3.0	G	G

Again, the 4BK and 5BK fines tended to improve the characteristics of the oat bran breads to a greater degree than 2 BK, and only 5BK equalled gluten when added at the lower level (Table 18). For the 20 and 25% oat bran breads, the higher levels of 4BK and 5BK fines improved loaf volumes and water absorptions to a greater degree than 5% gluten. Considering the differences in cost of producing gluten versus air classified fines, it appeared that wheat protein concentrates based on the dry process would be a very feasible and economic replacement for gluten in bread formulations.

15. SUMMARY AND CONCLUSIONS

1. All of the break and middling flours from two HRS flour mills could be reduced in particle size by fine grinding, and the light particles separated from the dense starch granules by the air classification process. Compared to the original flours, the fine fractions were enriched in protein, fiber, fat and ash while the coarse fractions of the air classifier cut contained more starch.
2. Two passes through the pin mill were necessary to reduce the HRS flour particles into the size range of starch granules, $<45\text{ }\mu\text{m}$ diameter. The degree of starch damage was proportional to the extent of roller milling, number of passes through the pin mill or setting of the attrition mill. Generally, the break flours exhibited much less starch damage than middling flours, and impact grinding on the pin mill caused more broken starch granules than the attrition milling processes. Future studies should be conducted on the available range of these types of grinder-classifiers.
3. Wheat flours and especially reground flours contained very high proportions of fine particles which contribute little to the total flour volumes. Thus, the image analysis system adopted in this study for measuring the particle size areas on microscopic slides, converting the areas to volumes, and calculating their proportions of total flour volume was a key element in the successful evaluation of the fine grinding and air classification system.
4. The pin- and attrition-milled flours were air classified at progressively wider vane settings and, on the basis of yield, particle size and chemical composition, it was possible to predict the optimum vane settings for separation of protein into the fines and starch into the coarse fraction. The degrees of protein shift were as high as 27% in the various experiments but degrees of starch shift did not exceed 7.5%. It would be desirable to increase protein shift, and attrition-type milling might achieve this. But the greatest gains need to be in the reduction of small starch granules and broken starch in the fine fraction. One of the achievements of the present project was to develop an extremely accurate procedure for quantitation of starch in wheat flours and other plant materials. The characterization of the starch in the fine fraction will be the object of future research.
5. The ability of the fine, high protein fraction (HPF) to replace commercial wheat gluten in bread formulations was evaluated in a wide range of flour

blends. The HPF or wheat protein concentrate (WPC) from 5BK flour substituted for gluten on an equal protein basis in soft wheat, Prairie Spring, HRS patent, HRS bakers' and triticale flour formulations. Similarly, the WPC from 3BK, 4BK and 5BK flours gave comparable or better results than gluten in the improvement of high fiber breads based on wheat or oat bran. The results using WPC from middling flours or 1BK and 2BK were less successful, due to their lower protein contents or weaker gluten-forming properties.

6. A most surprising result was that the coarse fractions from air classification of 3BK, 4BK and 5BK flours contained intermediate levels of protein and starch, which could be blended off into bakers' flours. This would have the effect of increasing their value to that of bakers' patent, and so both HPF and MPF would be value-added products from the process.
7. Because HRS wheats must be tempered to 16.0% moisture before milling, the moisture levels in the break flours average about 15%. A study was conducted to determine that the optimum moisture content for efficient air classification was about 5%. Therefore, drying studies were done on the flours to determine the maximum drying temperatures possible without damage to the bread-making properties of the gluten-forming proteins. In later experiments, it was found that two passes of the flours through the pin mill reduced the moisture contents quite substantially and the air classifier served to dry the flours even further. No benefit of artificial drying of the flours could be demonstrated in the air classifier, and so a costly pretreatment was found to be unnecessary.

16. REFERENCES CITED

- Dexter, J.E., K.R. Preston, A.R. Tweed, R.H. Kilborn and K.H. Tipples. 1985. Relationship of flour starch damage and flour protein to the quality of Brazilian-style hearth bread and remix pan bread produced from hard red spring wheat. *Cereal Foods World* 30:511.
- Gracza, R. 1960. The subsieve-size fractions of hard red spring wheat flour produced by air classification. *Cereal Chem.* 37:579.

17. PUBLICATIONS AND CONFERENCE PRESENTATIONS ON FINE GRINDING AND AIR CLASSIFICATION OF WHEAT FLOURS

Publications in Research Journals and Published Conference Proceedings

- Nowakowski, D., F.W. Sosulski, and R. Hoover. 1986. The effect of pin and attrition milling on starch damage in hard wheat flours. *Starch/Starke* 38: 253-258.
- Sosulski, F.W. and K. Sosulski. 1986. Composition and functionality of protein, starch and fiber from wet and dry processing of grain legumes. *Biological Effects, Composition and Chemistry*. Chapter 15. 14 pp. American Chemistry Society, Washington, D.C.

- Nowakowski, D.M., F.W. Sosulski and R.D. Reichert. 1987. Air classification of pin-milled break and middling flours from hard red spring wheat. *Cereal Chem.* 64: 363-370.
- Sosulski, F.W., A.F. Walker, P. Fedec and R.T. Tyler, 1987. Comparison of Air Classifiers for Separation of Protein and Starch in Pin-milled Legume Flours. *Lebensmittel-Wissenschaft und Technologie*, 20: 221-225.
- Sosulski, F.W., D.M. Nowakowski and R.D. Reichert. 1988. Effect of attrition milling on air classification properties of hard wheat flours. *Starke/Starch* 40: 100-104.
- Sosulski, F.W. 1989. Preparation and uses of vegetable food proteins made by dry processes. In *Proceedings of the World Congress on Vegetable Protein Utilization in Human Foods and Animal Feedstuffs*. T.H. Applewhite (ed.). American Oil Chemists' Society, Champaign, IL. pp 553-558.
- Sosulski, F.W. and D.M. Nowakowski. 1989. Processing and utilization of air-classified wheat flour fractions. In *Wheat Is Unique - Structure, Composition, Processing, End-Use Properties, and Products*. Y. Pomeranz (ed.). American Association of Cereal Chemists, St. Paul, MN. pp 431-444.

Conference papers and abstracts

- Nowakowski, D. and F. Sosulski. 1986. Functionality of protein concentrates from HRS wheat. *Symposium on Effects of Processing on Protein Quality*. 71st Annual Meeting of American Association of Cereal Chemists, Oct. 5-9, Toronto.
- Sosulski, F.W. 1987. Preparation and uses of vegetable food proteins made by dry processes. *Short course on Vegetable Food Proteins: Preparation, Modification and Utilization*. American Oil Chemist's Society, Food Protein Research and Development Center, May 14-15, Texas A&M University, College Station, TX.
- Nowakowski, D.M., F.W. Sosulski and R.D. Reichert. 1987. Effects of attrition milling on air classification properties of hard wheat flours. 72nd Annual Meeting of American Association of Cereal Chemists, Nov. 1-5, 1987, Nashville, TN.
- Sosulski, F.W. and D.M. Nowakowski. 1988. Pin milling and air classification of hard red spring wheat. *Proceedings of the 8th International Cereal and Bread Congress*, Lausanne, Switzerland, May 30-June 3, p. 76.
- Sosulski, F.W. 1988. Preparation and uses of vegetable food proteins made by dry processes. *Proceedings of the 1988 World Congress on Vegetable Protein*, Singapore, Malaysia, October 2-7, 1988.
- Sosulski, F.W. 1988. Processing and utilization of air-classified wheat flour fractions. *Proceedings of the Wheat Industry Utilization Conference*, San Diego, CA, October 7-8, p. 21.

Sosulski, F.W. 1989. Air-classified wheat protein concentrates. Fifth International Congress of Engineering and Food Cologne, FRG. May 25-June 3.

Theses

Nowakowski, D. M.Sc. thesis. Effect of grinding methods on air classification of break and reduction flour from hard red spring wheat. University of Saskatchewan, Saskatoon, 1986.

Abdel-Aal, E.-S. Ph.D. thesis. Formulation and evaluation of novel, nutritious and economical products from cereal, legume and oilseed blends. University of Alexandria, Egypt, 1988.

Seminars and News Releases

Potential of pin milling and air classification of cereals and legumes for food processing in China. Grain Science Research Institute, Beijing, China. Dec. 7-19, 1987.

Dry process alternatives to wet milling and extraction of protein, oil and starch. Department of Chemical Engineering, Saskatoon, Feb. 8, 1989.

Revolution in the wheat milling system. Information Services, Saskatchewan Agriculture. June 9, 1987.

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